The Gully Ecosystem

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by

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ABSTRACT

R.J. Rutherford and H. Breeze. 2002. The Gully Ecosystem. Can. Manuscr. Rep. Fish. Aquat. Sci. 2615: vi + 30 pp.

This report describes the features and current understanding of the ecology of the Gully, based on research in this and other submarine canyons. It is a theory of how The Gully ecosystem works. This explanation is the basis for the Gully management plan. It will remain the foundation for management decisions until further scientific studies show there is a need for changes.

RÉSUMÉ

R.J. Rutherford and H. Breeze. 2002. The Gully Ecosystem. Can. Manuscr. Rep. Fish. Aquat. Sci. 2615: vi + 30 pp.

Le présent rapport décrit les caractéristiques du Goulet et les connaissances actuelles sur son écosystème, d'après les recherches qui ont été effectuées à propos de ce canyon et d'autres canyons sous-marins. Il s'agit d'un exposé théorique sur la façon dont l'écosystème du Goulet fonctionne, qui est à la base du plan de gestion du Goulet. Ce document continuera de servir de fondement aux décisions de gestion tant que de plus amples études scientifiques n'auront pas établi que des changements sont nécessaires.

INTRODUCTION[1]

A group of northern bottlenose whales can be found year-round in a small patch of ocean, 370 kilometres east of Halifax. There are 130 individuals who frequent The Gully and about 44 can be found in an 8 kilometre by 25 kilometre core area at any one time. This area and a region off Labrador are the only areas where this whale species (Figure 1) is regularly sighted in the Northwest Atlantic.

Why are the whales commonly found here and in the surrounding region, yet seldom sighted in other parts of the Scotian Shelf?

These whales centre their activities around the mouth of The Gully, a long, deep, underwater canyon about 40 kilometres east of Sable Island (Figure 2). Other species of marine mammals are also frequently sighted in the area, deep-diving toothed whales in particular.

The Gully is the largest submarine canyon in the western North Atlantic and one of the deepest: about 40 kilometres long, 16 kilometres wide, and more than 2500 metres deep. The canyon extends about 40 kilometres into the Scotian Shelf, through the outer banks of the shelf, and into the middle shelf. At the head of the canyon is an area known as the Trough (Figure 3). It is a wide and relatively shallow basin that links the canyon with inner regions of the Scotian Shelf. While there are other submarine canyons along the edge of the Scotian Shelf, none of them are as large as The Gully, cut between two shallow banks, have a trough area at the head, nor stretch as far back into the shelf. Because of its shape, size, and physical oceanography, The Gully contains many diverse habitats and is highly productive.

The diversity of habitat in The Gully results in a diversity of species. Within this fairly small area are deep-diving, squid-eating whales, seabirds that pluck fish from surface waters, marine worms that live in soft mud, corals that are attached to rocks and boulders, and many other species and assemblages of species. The Gully has shallow water and very deep water species in close association. The shape and physical properties of The Gully encourage this diversity.

Figures on The Gully

Location: 200 kilometres off Nova Scotia
Depth: more than 2500 metres at deepest point
Canyon Width (at mouth): 16 kilometres
Canyon Length: 40 kilometres
Trough Width (east-west): 70 kilometres
Trough Length (north-south): 30 kilometres

Northern bottlenose whales feed primarily on squid, particularly those from the genus *Gonatus* (*G. fabricii* or *G. steenstrupi*), and on deep-sea fish. To sustain their large bodies, the whales eat at least 300 squid each day. Multiplied by 44 whales, this adds up to an astounding 13,200 squid consumed by whales in the canyon each day.[2] Yet the whales stay in the region year-round and are able to find enough food in this relatively small area. They are just one of several species of whales and dolphins that also frequently use the area.

How is this relatively small, 200 square-kilometre patch of ocean able to sustain several dozen large animals year-round, other whales and dolphins, the squid and fish they prey on, and countless other species?

This report explains some of the reasons why The Gully is highly used by marine mammals. It describes the features and current understanding of the ecology of The Gully, based on research in this and other submarine canyons. A footnote at the head of each section or subsection lists the major sources of information for that section. A list of bibliographic material

[1] Sources for this section: Gowans et al. (2000) and Hooker et al. (2002).

[2] This is a conservative estimate given by Hooker et al. (2002). Other estimates have been even higher: Clarke and Kristensen (1980) estimated that northern bottlenose whales might eat 4 percent of the body weight each day, or about 600 squid

INTRODUCTION[1]

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The diversity of habitat in The Gully results in a diversity of species. Within this fairly small area are deep-diving, squid-eating whales, seabirds that pluck fish from surface waters, marine worms that live in soft mud, corals that are attached to rocks and boulders, and many other species and assemblages of species. The Gully has shallow water and very deep water species in close association. The shape and physical properties of The Gully encourage this diversity.

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[2] This is a conservative estimate given by Gowans et al. (2002). Other estimates have been higher. Clarke and Kristensen (1981) suggested that northern bottlenose whales might consume 3 per cent of the body weight each day, or about 1 tonne of squid.

Figure 1. Photo of a northern bottlenose whale taken in The Gully (copyright Hal Whitehead Research Lab). Northern bottlenose whales are about 6.5 to 9 metres long and weigh from 6 to 8 tonnes.

Figure 2. Location of The Gully off eastern Canada.

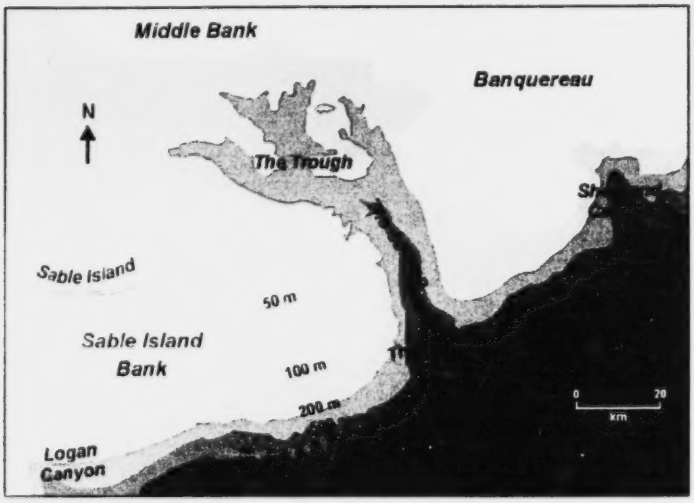

Figure 3. The Gully and nearby features.

is provided at the end. Much of our understanding of The Gully is preliminary, especially our understanding of the deep water habitats. Further research may change some of our understanding of this special area.

During its review of "The Gully: A Scientific Review of Its Environment and Ecosystem" (Harrison and Fenton 1998) Fisheries and Oceans Canada's Regional Assessment Process (RAP) recommended that a chapter be included that synthesized and integrated the various chapters into an overview of The Gully ecosystem. The reviewers commented, "This chapter should be fairly general and brief and can draw heavily on existing papers... It should also deal with flows into and out of The Gully and trophic energy flows and relationships. It needs to be written in a 'readable' and 'story-like' manner" (Keizer 1998, p. 21).

It has been increasingly evident that such a document is essential to the development of a management plan for the area. What is presented here is aimed at filling this need. It is a theory of how The Gully ecosystem works. It is based on enduring features and processes well known in temperate marine ecosystems and ground-truthed by observations and facts collected by researchers and fishermen who have worked in The Gully area. This explanation of how The Gully ecosystem works is the basis for The Gully management plan. It will remain the foundation for management decisions until further scientific studies show there is a need for changes.

HUMANS AND THE GULLY[3]

The large size of The Gully has made it an obvious feature on oceanographic charts, as well as a subject of fisheries and scientific interest. In the late 1800s, fishing boats from Gloucester, Massachusetts travelled regularly to The Gully's rich halibut grounds. Directed scientific research came somewhat later. Geologist J.I. Marlowe carried out one of the earliest studies in the mid-1960s. He collected rock samples, drilled cores, and took echosounder information from the canyon. Until recently, few other studies were carried out in The Gully, with the notable exception of the studies of northern bottlenose whales carried out by Dalhousie University researchers.[4]

Although there were few studies of the area, there was an increasing sense that something special was happening in The Gully. Conservation groups became interested in the area in the mid-1980s. The area was included as a potential area for protection in the Parks Canada review of Atlantic Canada. The Canadian Wildlife Service released a discussion paper on a conservation strategy for the area after a 1994 workshop on The Gully. A 1998 review led by Fisheries and Oceans Canada (DFO) described the state of knowledge on The Gully. It was subsequently identified as an Area of Interest under DFO's marine protected areas program in late 1998 and a conservation strategy was released at the same time. This identification led to more research on The Gully, in an effort to better understand the processes occurring in the canyon and the marine organisms found there. It has become one of the best-studied deep water ecosystems in Atlantic Canada.

[3] Sources for this section: Breeze (in prep.), DFO (1998), Gordon and Fenton (2002), GTA Consultants (1999), Harrison and Fenton (1998), and Marlowe (1965).

[4] Research vessels from the Woods Hole Oceanographic Institution regularly visit The Gully to conduct student research projects during the summer. These studies are not published.

FORMATION OF THE GULLY[5]

The ancestor of The Gully first appeared as part of a drainage system in pre-glacial times, more than 30 million years ago and perhaps much earlier. At this time, much of the shelf was above sea level. The Gully's form was further shaped by oceanographic processes occurring over millions of years. The movements of glacial ice and erosion from glacier meltwater determined the shape of much of the eastern Scotian Shelf, including The Gully, with the most powerful erosion processes likely occurring 150,000 and 450,000 years ago. The canyon provided a drainage channel for both ice and water, and the erosion caused by these processes shaped the canyon and the distribution of surficial sediments found on the underlying bedrock. There are several smaller "feeder" canyons along the western side of The Gully that provided drainage channels into the larger canyon.

Along the walls of the canyon, in depths less than 800 metres, there are lines of steep cliffs and broad terraces, likely shaped by movements of glaciers thousands of years ago (Figure 4). Boulders deposited by glaciers are found above depths of 800 metres. There are large areas of exposed bedrock, mostly siltstone, sandstone, and mudstone. This contrasts with most other areas of the outer Scotian Shelf, which either do not have exposed bedrock or have much smaller exposed areas. Exposed bedrock cliffs, rock ledges and terraces are also a feature of The Gully feeder canyons.

Iceberg scour pits are common above depths of 800 metres. These pits were caused by icebergs grounding against the sides and terraces of the canyon during the late Wisconsian, about 20,000 years ago. Below 800 metres in depth, there is no evidence of ice directly shaping the canyon. At

[5] This section is based on interpretation of Amos (1989), Amos and Nadeau (1988), Atlantic Geoscience Society (2001), Fader et al. (1998), Fader and Strang (2002), Marlowe (1965), Mudie (1990), and Sankerelli and Fader (1999).

those depths, The Gully has a ridge-and-valley form, with walls sloping relatively smoothly to the canyon floor. This shape is maintained by the actions of currents.

Currents in The Gully are strong and are actively shaping the canyon. Many areas of The Gully are much steeper than adjacent areas of the continental slope, providing evidence that currents within the canyon are more intense than nearby areas. Strong near-bottom currents carry sediments, nutrients, and detritus down to deeper parts of the canyon.

There are large areas of sand-waves and mega-ripples in the northern part of the inner Gully at depths between 200 and 400 metres. These formations are too deep to be influenced by waves. Instead, currents are the key agent of sediment movement. The sand waves indicate that sediments are continually moving into the canyon from areas to the north, carried by strong bottom currents.

The circulation patterns over Banquereau and Sable Island Banks tend to allow only fine suspended materials to pass along the ocean bottom and into The Gully. There are some exceptions. The Sable Island Bank (western) side of The Gully is indented by nine smaller canyons, called "feeder canyons." Seven of these canyons are active drainage channels, providing a path for larger sediments, such as sand, as well as fine organic materials to move via bottom currents from Sable Island Bank into The Gully.

The other two feeder canyons have sand deposits across their mouths where they enter the Trough area, indicating that sediment and current flows are not as strong or perhaps not as deep as they once were. Underwater photos show that there is still a general flow through these canyons toward The Gully. These two feeder canyons have their own habitat features, their lower flow levels distinguishing them from the other feeder canyons. All nine feeder canyons extend from parts of Sable Island Bank exposed 20,000 years ago during the time of glaciers, supporting the theory that The Gully was formed and maintained by erosion caused by water and ice. Smaller channels along the edge of The Gully also provide a path for sand to move off Sable Island Bank and into The Gully.

To the north of the canyon, channels show a path where bottom currents flow from the inner shelf and the Trough into the canyon. These channels provide another path for sediments to move into the canyon.

The eastern side of The Gully, next to Banquereau, has no large feeder canyons. On that side of The Gully, only fine-grained sediments and suspended organic materials are transported into the canyon, such as silt, mud, very fine-grained sand, and fine organic detritus (marine snow).

The type of sediment found in a particular location is an important factor in determining the organisms that are found there. The variety of sediment types found in The Gully leads to a diversity of bottom-dwelling organisms. Organisms that live in soft muddy sediments, as well as those preferring the varied topography or hard substrate of cobbles, boulders, and exposed bedrock, can all find suitable habitat. The characteristics of the water column, such as current velocity, temperature, and salinity, are also important factors in determining which organisms are found in a particular area. The characteristics of water and its movements also determine which sediments are found in particular locations and how stable they are.

CURRENTS AND TIDES: THE FORCES BEHIND THE GULLY ECOSYSTEM[6]

The steep topography of The Gully influences the currents flowing through the canyon and the mixing of waters within it. The currents within The Gully are quite complex and not completely understood. Researchers studying American submarine canyons have found that large, long canyons with deep mouths at the shelf break (200-metre isobath) have strong, bidirectional currents. Smaller, shallower canyons have weaker currents and are less energetic environments. The Gully fits the pattern of long, large canyons.

The Gully connects the edge and slope of the Scotian Shelf to the inner part of the shelf. It acts as a conduit for waters found on the slope and shelf edge. The amount of water passing through The Gully varies seasonally.

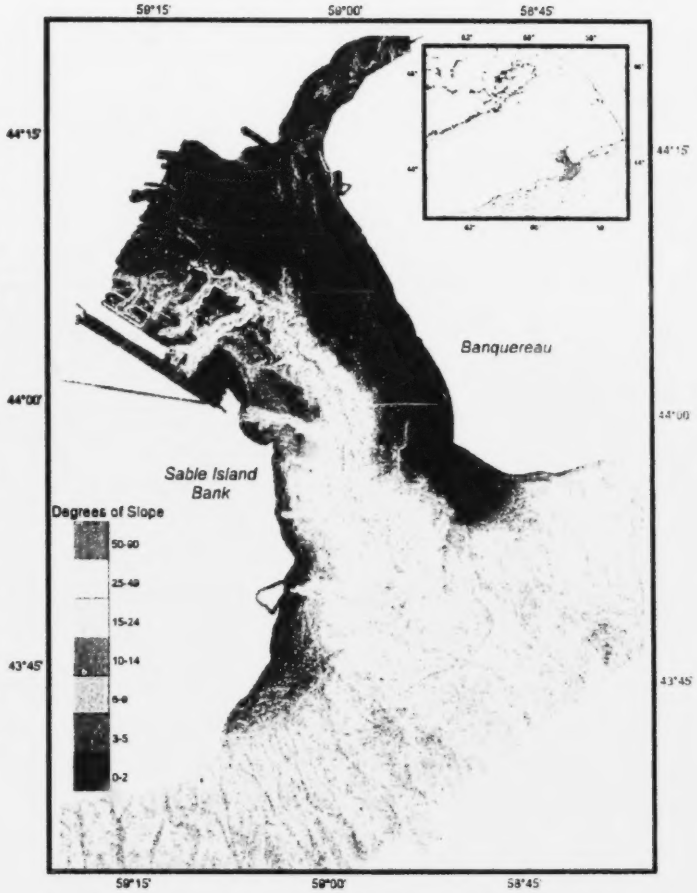

Figure 4. Degree of slope along the walls of The Gully and adjacent slope. The steepest slopes in the region (50 to 90 degrees) occur along the walls of the canyon (Source: Fader and Strang 2002).

Major Currents

The Scotian Shelf is most strongly influenced by three currents. A cool, southwestward flowing current, the Nova Scotia Current, flows out of the Gulf of St. Lawrence. Some of it turns westward at Cape Breton to flow along Nova Scotia's Atlantic coast, the rest continues toward the shelf break. A second cool, southwestward flowing current, the Labrador Current, flows from the Labrador Sea and around the Grand Banks. It joins with the cool outflow from the Gulf of St. Lawrence at the Laurentian Channel and runs along the edge of the Scotian Shelf. The third current is the warmer, saltier Gulf Stream, which flows south of the Scotian Shelf in a northeastwards direction (Figure 5). The differences in temperature and salinity between these currents are the major forces behind the circulation on the shelf itself. Current flow is also strongly influenced by the topography of the ocean bottom.

The Labrador Current and Gulf Stream are deep currents extending down to depths over 3000 metres. Because of the earth's rotation (Coriolis Force), the Labrador Current has a tendency to pull to the right as it flows along the shelf edge. Some water from

[6] This section is based on interpretation of Butman (1989), Han et al. (1997), Han et al. (2002a), Han et al. (2002b), Harding (1998), Mann (2002), Petrie et al. (1998), Sandstrom (1991), Sandstrom and Elliott (2002), Sandstrom and Oakey (1995), and Valentine (1989).

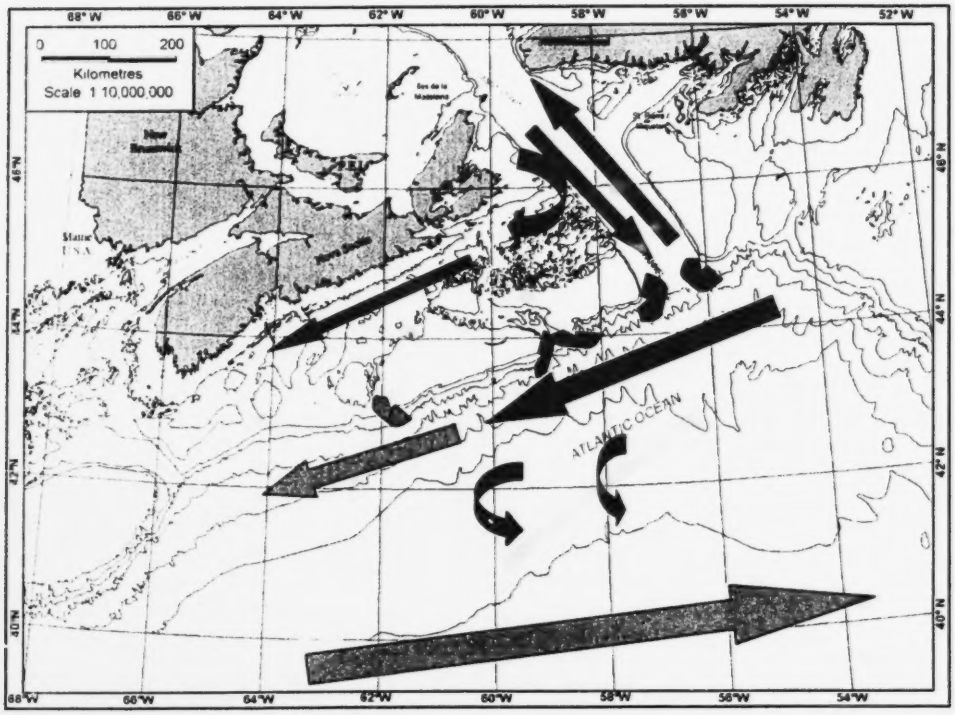

Figure 5. Generalized schematic of near surface currents on the Scotian Shelf and Slope.

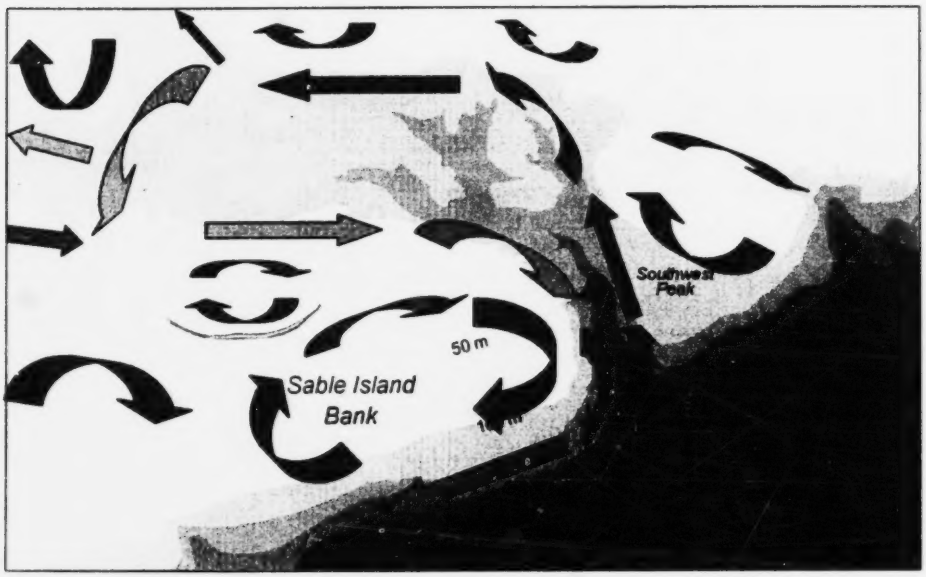

Figure 6. Generalized schematic of currents in the vicinity of The Gully. During the summer, fall, and winter, the circulation in the centre of The Gully forms a leaky gyre, while in the spring, a higher volume of water passes through The Gully and the gyre-like tendencies become weaker.

the current is forced downward (downwelling), creating flows down the slope.

Bidirectional Currents

When the shelf edge current reaches The Gully, part of it turns into the canyon and flows along the southwestern side of Banquereau. At depths greater than about 360 metres, the current is forced to turn by the steep slope at the head of the canyon. The volume of water that turns and the strength of the flow at various depths depend on many factors, including the steepness of the slope. The current continues to turn to the right against the canyon sides, causing a downward flow along the walls and toward the bottom. Some of this downward flow is thought to form a current at the bottom of the canyon that flows along The Gully floor like a meandering river. The floor of the canyon is not very steep, with an average gradient of about 2 percent. The remainder of the downward flow upwells in the centre of The Gully.

Above depths of about 360 metres, the current continues toward the head of the canyon and onto the shelf. Part of this flow flows south and west of Middle Bank, joining the Nova Scotia Current along the coast. Part of this flow is turned in a counterclockwise direction south of Middle Bank, flowing along the north and west sides of Sable Island Bank and out of The Gully. In the summer, fall and winter, the flows into and out of The Gully are approximately equal. In the spring, a much higher volume flows through The Gully and onto the shelf.

The flow above depths of about 180 metres interacts with the circulation on the shallow banks surrounding The Gully. Tidal currents washing over the banks of the Scotian Shelf cause steady currents, resulting in a mean clockwise circulation around the edge of the banks. The interaction of the flow through and around The Gully with the bank circulation results in upwelling areas. As well, some of the clockwise bank circulation joins the flow around and out of The Gully.

The clockwise circulation around the edge of the banks generally prevents all but fine suspended particles from moving off the banks. However, near-bottom currents carry some particles, with the feeder canyons cutting into Sable Island Bank providing an important mechanism for off-bank flow. These circulation patterns mean that sinking phytoplankton, small animals and bacteria-covered organics (marine snow) are drawn down from the banks and trough into The Gully by currents moving along the bottom. Much of this organic material is carried toward the canyon along "mud" channels in the Trough. These mud channels are known to be good places to fish for groundfish. Fish stay there to feed on the smaller fish and invertebrates that are eating organic debris and plankton that have collected in the channels.

Retention of Particles

The opposing currents, one flowing northwestwards on the Banquereau side of The Gully and one flowing southeastwards on the Sable Island Bank side, cancel each other out in the centre. The net result is a partial counterclockwise gyre and a deep-water area that retains particles and weakly swimming marine life, i.e., plankton.

The Gully's counterclockwise gyre exists during the summer, fall and winter (Figure 6). In the spring, the difference between the lower density, fresher water on the inner shelf and the higher density, higher salinity water off the shelf causes a strong flow of off-shelf water to be drawn in through The Gully. This flow can bring twice as much water in as flows out. The in-flowing current draws from depths exceeding 700 metres. This results in strong upwelling at the head of The Gully. However, there is likely to be gyre-like circulation that retains particles below depths of about 700 metres in The Gully during all seasons.

The spring flow from the shelf edge follows much the same path though the Trough but with an extra branch flowing between Banquereau and Middle Banks toward Canso Bank. This flow and the strong flow along the southwestern side of Middle Bank join the Nova Scotia Current on the inner shelf. The flow from off-shelf brings nutrients to the surface, helping to fuel the spring bloom of phytoplankton. It also provides a mechanism for organisms overwintering in The Gully to be distributed to other parts of the shelf.

In general, retention zones are considered to be biologically important as they concentrate particles and keep weakly swimming animals and young, such as fish larvae, near their food. Areas of retention also allow the eggs and larvae of bottom-dwelling animals to remain near areas with preferred bottom characteristics. The Gully is the largest such deep-water area in Atlantic Canada and a key habitat for deep-water species.

Internal Waves

In the summer and early fall, water over much of the shelf is highly stratified. A warmer, less dense water layer overlays a cooler, denser layer of water. The interface between the warm water and the cool water is called the thermocline. Nutrients in the surface layer cannot be replenished from deeper waters and phytoplankton levels are low (see "The Gully Food Web" section for further details). However, at the shelf edge, different conditions prevail. There, the steep topography interacts with the twice-daily tides to cause internal waves that regularly mix the water layers across the thermocline. Nutrients are brought into the euphotic zone and phytoplankton are drawn down into deeper layers. This regular mixing results in high phytoplankton levels in The Gully at depths of 30 to 40 metres and a high level of primary productivity.

The energy from the internal waves is higher on the Banquereau side of The Gully and the Southwest Peak of Banquereau than on the western side of The Gully. Mixing caused by internal waves, in all areas of The Gully, is among the highest observed anywhere on the Scotian Shelf.

Transport of Organic Material

The productivity from the surrounding banks and The Trough feed into the canyon. The Southwest Peak of Banquereau has a particularly high level of tidal mixing and is highly productive. The productivity from Banquereau feeds primarily into the Trough but also into valleys on the northwest side of The Gully. The feeder canyons from Sable Island Bank allow for a large volume of suspended organic materials to pass into the canyon. Productivity from Middle Bank and the small banks in the Trough follow the bottom drainage pattern to The Gully.

Circulation on the Slope

The mixing of waters from the warm salty Gulf Stream with cooler waters from the Labrador Current creates the water mass known as warm slope water. This water mass lies over most of the Scotian Slope. Slope waters occasionally move into the deep water layers of The Gully, particularly during the summer and fall. In some years this water mass may dominate, depending on oceanographic conditions. These waters are warmer and saltier than the waters from the Gulf of St. Lawrence and Labrador Current.

The interaction of the shelf edge flow with the warm slope water creates a large, counter-clockwise flow south of Newfoundland and along the Scotian Slope. This circulation may entrain animals associated with the Gulf Stream and provide a mechanism for them to be carried into Atlantic Canadian waters.

Complex Water Movements

Although finer details of currents and water movement are not well understood, overall, The Gully is a highly energetic environment. This results in a high degree of mixing of waters in the canyon. The complicated pattern of currents also results in areas of deep water retention that concentrate particles and weakly swimming organisms. The canyon benefits from the productivity of the adjacent banks and trough. Food, in the form of marine snow, is continually carried into the canyon by near bottom currents, resulting in high numbers of organisms in the canyon.

THE GULLY FOOD WEB

The Gully supports many different organisms at all of its depths. Some of these species travel from surface waters to the deepest parts of The Gully. Others have a much smaller range of vertical movement, living most of their lives attached to the sloping sides of the canyon, or within a span of tens of metres in the water column. The Gully's range of depths and varied sediments result in a great diversity of habitats and species (Figure 7).

The pressure in deep parts of The Gully is immense, as it is in all deep water areas. As a demonstration, styrofoam coffee cups were lowered to a depth of 1200 metres from DFO's research vessel, C.C.G.S. Hud-

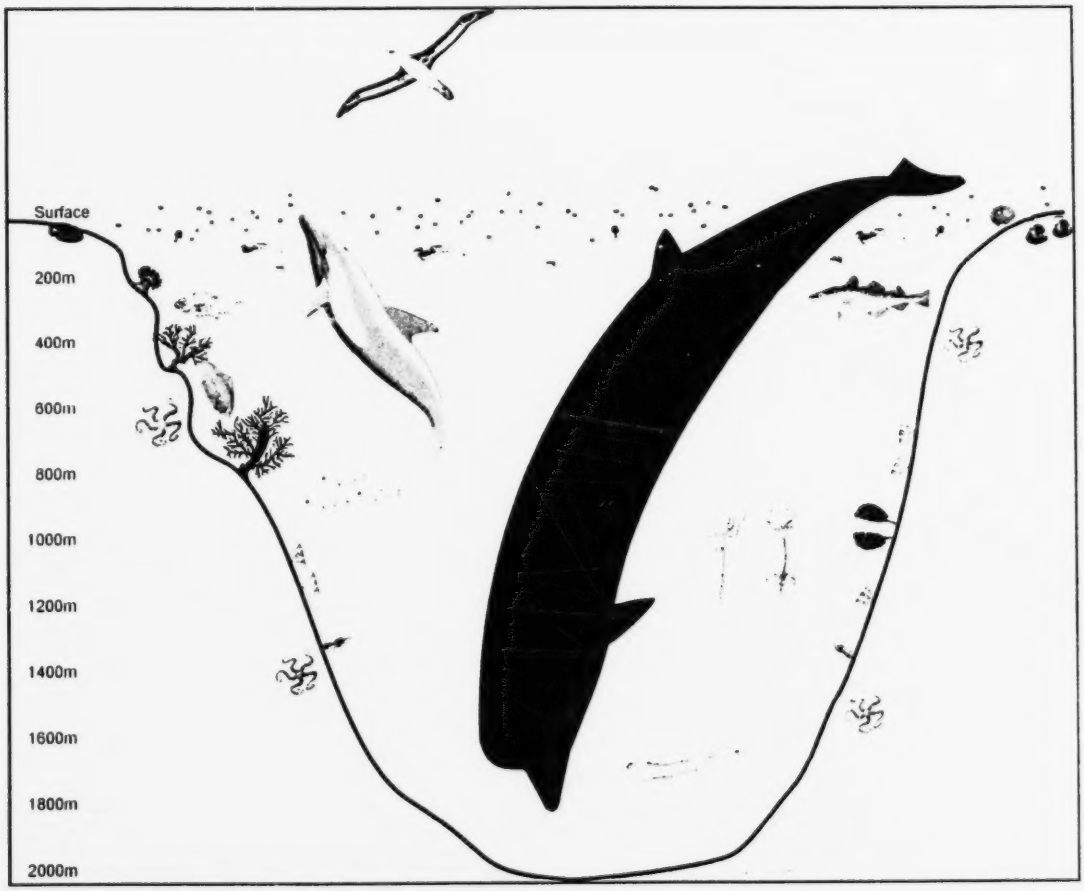

Figure 7. A stylized cross-section of The Gully, showing some of the organisms that live there at different depths.

son, in the summer of 2000. When brought back aboard, the cups had shrunk to about half their original height and could hold even less than a quarter of their original volume (Figure 8). Fish that are pulled up from these depths die because their swim bladders[7] expand and burst from the rapid change in pressure. Animals living in the deepest parts of the canyon have special adaptations to withstand changes in pressure, especially if they travel from the surface waters to great depths. Humans can only visit these depths in research submarines. They also use video and still cameras lowered from ships, specially designed sampling equipment, and remotely operated vehicles to observe the marine life of submarine canyons.

Figure 8. Photo showing a regular styrofoam cup next to one lowered into The Gully.

The Water Column: Surface and first 180 metres[8]

The surface waters of The Gully support a rich life, much of it microscopic. Tiny phytoplankton are the basis of the food web in the oceans. They need both nutrients and light to reproduce. They must spend enough time in depths where sufficient light penetrates the water column to allow photosynthesis to occur (the euphotic zone). Phytoplankton are food for zooplankton that in turn provide food for other organisms.

The conditions that support phytoplankton productivity have been studied in some detail around the world. Globally, areas with periods of strongly stratified waters alternating with periods of enhanced vertical mixing have been found to support high numbers and biomass of phytoplankton.

During periods of stratification, phytoplankton are held in surface waters with high light levels. For example, on the Scotian Shelf during the early spring, the surface water of the ocean begins to warm. During the spring and summer, a warm layer of water lies over a layer of cooler, denser water in most areas of the shelf. Phytoplankton are carried by the movements of water and are held in the top layer which does not mix with the more dense layer below. As long as there are ample nutrients, the phytoplankton in the surface layer will grow quickly. As nutrients are exhausted, growth slows and the number of phytoplankton decreases.

During periods of vertical mixing, nutrients are brought into the surface layers of the ocean. However, this mixing also carries some of the phytoplankton out of the euphotic zone. Growth of phytoplankton slows because there is not enough light for photosynthesis, although there are ample nutrients. If the period of vertical mixing, when nutrients are replenished, is followed by a period of stratification, when plankton are held within the euphotic zone, productivity will be high.

There is a "bloom" of large phytoplankton in the spring over most of the Scotian Shelf,

[7] The swim bladder is an organ that helps fish regulate their depth in the water column.

[8] This section is based on interpretation of Alldredge and Gotschalk (1990), Davis and Browne (1996), Frank and Page (1998), GTA Consultants (1999), Harding (1998), Head and Harrison (1998), Kepkay et al. (2002), Kiørboe (2001), Lock (1998), Mann (2002), Mann and Lazier (1996), O'Boyle et al. (1984), Shanks and del Carman (1997), Vetter (1995), Vetter (1998), Weatherbee (1997), and Whitehead et al. (1998).

including The Gully. This bloom sinks to deeper nutrient-rich water in the late spring as the phytoplankton run out of nutrients in the surface layer. The large phytoplankton seen in the surface waters during the spring are replaced by smaller species in the early summer.

In The Gully, the twice-daily tides generate internal waves that mix nutrient-rich water into the euphotic zone along the thermocline. This mixing does not extend to the surface but provides nutrients for a rich phytoplankton growth 20 to 40 metres below the surface. Some of this productivity is drawn down to deeper waters during the mixing and becomes marine snow, supporting the food web below.

There is a smaller bloom of phytoplankton in surface layers in the fall across the Scotian Shelf, including The Gully. This bloom is due to increased mixing of waters brought on by cooling surface water and more frequent storms. Increased mixing replenishes nutrients in the surface waters. In winter, levels of light are low and phytoplankton grow and divide much more slowly than they do in the spring and fall.

Productivity from phytoplankton is only part of the story of The Gully's productivity. The Gully benefits from primary and secondary production both within The Gully and from production in the Trough and adjacent banks. Dead phytoplankton, zooplankton and other organisms from the surface are carried through the water column and are decomposed by bacteria. This detritus becomes aggregations of plankton and decomposing materials known as marine snow. Currents carry these suspended organic materials from the Trough, Sable Island Bank, and Banquereau into The Gully. The export of organic materials from nearby areas into the canyon fuels high secondary production in The Gully. Marine snow is an important source of food for zooplankton, fish, and other marine organisms found in the water column. Detritus that continues to the ocean bottom provides food for bottom-dwelling fish and invertebrates.

The microplankton, zooplankton less than 200 micrometres,[9] prey on phytoplankton and are a link between phytoplankton and the larger species of zooplankton. Less is known about these species than the larger zooplankton species. The mesozooplankton, between 200 and 2000 micrometres in size, have been much more extensively studied than the smallest zooplankton.

The most important group of the mesozooplankton are the copepods. These tiny crustaceans make up about 80 percent of the total mesozooplankton biomass in the Northwest Atlantic. On the Scotian Shelf, the most important copepod, in terms of biomass, is *Calanus finmarchicus*. *C. finmarchicus* overwinters in waters deeper than 200 metres in the basins of the Scotian Shelf and along the shelf edge. They spend the spring and summer in shallow waters over banks. Most of these copepods move to overwintering depths in the late summer and high numbers of *C. finmarchicus* have been sampled in The Gully during the late summer and fall in depths greater than 200 metres. The cold water copepod *Calanus hyperboreus* has a similar life history to *C. finmarchicus* and is also found in The Gully. Current flow along the shelf edge and through The Gully during spring distributes some of the overwintering *Calanus* to other parts of the Scotian Shelf.

During the late summer and fall, smaller species of copepods become more predominant in the surface zooplankton of the Scotian Shelf. *Centropages typicus*, *Pseudocalanus* spp. and *Nannocalanus minor* are common copepods in surface waters at this time of year.

Other invertebrates found in the top 200 metres of The Gully include amphipods, isopods, mysid shrimp, floating snails

[9] A micrometre (µm) is equal to one one-millionth of a metre or one one-thousandth of a millimetre.

Table 1. Fish eggs and larvae sampled from stations in or near The Gully, 1978-1982 (adapted from Frank and Page 1998)		
Species complex*	**# of eggs/m^3**	**# of larvae/m^3**
Cod/haddock	6	n/a
Cod/haddock/witch flounder	38	n/a
Cusk/mackerel	6	n/a
Cunner/Yellowtail flounder	13	n/a
Silver hake/longfin hake/white hake/butterfish/four-beard rockling	19	n/a
Species	**# of eggs/m^3**	**# of larvae/m^3**
Atlantic halibut	1	0
Argyropelecus sp. (silver hatchetfish)	0	1
Barracudina	0	1
Bathylagus compsus (deep sea smelt)	0	1
Bothus sp. (left-eye flounder)	0	1
Cardinalfish	0	1
Cod	16	9
Coral dragonet	0	1
Cusk	6	0
Four-beard rockling	3	5
Glacier lanternfish	0	10
Gulf Stream flounder	0	1
Haddock	3	0
Herring	0	1
Horned lanternfish	0	1
Lanternfish sp.	0	10
Longhorn sculpin	0	2
Mackerel	2	3
Monkfish	0	3
Offshore hake	3	0
Pollock	14	1
Plaice	17	3
Protomyctophum sp. (lanternfish)	0	1
Redfish (live young)	n/a	23
Sand lance	0	30
Sculpin sp.	0	1
Silver hake	27	29
Spotted lanternfish	0	1
Triglops sp. (sculpin)	0	1
Urophycid hake sp.	6	14
Windowpane	1	4
Witch flounder	1	12
Wolffish	0	1
Wrymouth	0	1
Yellowtail flounder	4	10
species unidentified	16	16

*At the earliest stages of egg development, exact identification to species level is not possible for many species. The species that cannot be discriminated from one another are grouped together. In the later egg and larval stages, these complexes are not applicable and species are listed individually.

(*Janthina* spp.), argonauts and other swimming molluscs (octopi, squids and similar creatures), box jellies, and comb jellies. Goose barnacles are occasionally found attached to floating objects.

Fish eggs and larvae are part of The Gully plankton community. The Scotian Shelf Ichthyoplankton Program sampled ten stations in The Gully between 1978 and 1982 and identified 12 species of fish eggs and 30 species of fish larvae. The species and number of eggs and larvae collected over the period of the survey are listed in Table 1. Of the species sampled in The Gully, the eggs and larvae of silver hake and lanternfish were most abundant. Deep water fish species with eggs that remain deep in the water column, rather than floating near the surface, are also likely to spawn in The Gully.

Swordfish and several species of tuna are found in the surface waters of the shelf edge and the mouth of The Gully when waters warm in the early summer. These large, epipelagic fishes migrate from their wintering areas further south. They feed on many different species, including small, schooling fishes, krill, silver and white hake, squid and barracudinas. Sharks, particularly porbeagle, blue and mako, are also common at the shelf edge near the mouth of The Gully.

Seabirds pluck small fish, such as herring, capelin and sand lance, from surface waters. Some birds dive in pursuit of fish and squid. Others, such as phalaropes, eat planktonic crustaceans that collect in slicks on surface waters. Shearwaters and storm-petrels are common seabirds of The Gully during the summer, while auks, fulmars and kittiwakes are found there during the winter. The birds are commonly found near the mouth of The Gully, at the edge of the Scotian Shelf.

Whales feed, rest, travel, and socialize in surface waters of The Gully. Several species of whales found in the area dive to great depths to feed on fish and squid, and they are discussed later in this report. The whale and dolphin species that have been sighted in The Gully are listed in Table 2. Several whales and dolphins are not listed that are likely to visit the area at least occasionally: pygmy and dwarf sperm whales, harbour porpoises, white-beaked dolphins, killer whales, Risso's dolphins and Fraser's dolphins. The overall diversity of whales in The Gully is highest in the summer and fall, when waters are warm. However, northern bottlenose whales remain in the area year-round and individual whales of other species may also be found there in the winter and spring.

Table 2. Whales and dolphins sighted in The Gully (adapted from Whitehead et al. 1998)

Species	Average depth of water in area sighted*
Blue whale	919 metres
Fin whale	923 metres
Minke whale	166 metres
Sei whale	no information
Humpback whale	1012 metres
Sperm whale	731 metres
Northern bottlenose whale	1196 metres
Mesoplodon spp. (beaked whales)	no information
Long-finned pilot whale	946 metres
Striped dolphin	1378 metres
Atlantic white-sided dolphin	1171 metres
Short-beaked common dolphin	1097 metres
Bottlenose dolphin	949 metres

*Observers were researching northern bottlenose whales and generally spent more time over the deep waters that those whales prefer. Many of these species can be found over shallow waters as well.

Minke whales filter small, schooling fish and zooplankton from surface and near-surface waters. Minkes are distributed widely across the Scotian Shelf. They have been observed near The Gully in areas with a depth of less than 200 metres. Like the minke whales, sei whales usually filter feed in surface waters. They eat copepods and other zooplankton. Humpback whales feed in surface and near-surface waters on krill and schooling fish. The dolphins of The Gully feed in both surface and mid-water depths. They eat fish and squid, taking prey that is plentiful.

Fish and Invertebrates of the Water Column below 180 metres and above 1000 metres (Mesopelagic Species)[10]

Many mesopelagic animals live at depths of 500 to 1000 metres in the water column during the day, and rise to surface waters at night to feed. By migrating to surface waters, these animals can take advantage of surface productivity. Species of shrimp, amphipods, octopi, squid, and fish can be found in the mesopelagic realm of The Gully.

One better known group of mesopelagic species are the euphausiids, also known as krill or krill-shrimp due to their resemblance to shrimp. The most common species off Nova Scotia are *Meganyctiphanes norvegica*, *Thysanoessa rashii* and *T. inermis*. They can be found in areas deeper than 200 metres in The Gully during daylight hours. These zooplankton are larger than copepods, about 1 to 3 centimetres in size, and feed on copepods and phytoplankton. They are common at the head of The Gully and in the "arms" of the Trough (see Figure 9). Researchers have found very high densities of krill in the deep waters of submarine canyons along Georges Bank, southwest of the Scotian Shelf. Scientists suggest that the depth and steep topography of the canyons combine with the krill's behavioural ecology to result in high densities of krill.

Krill are found in deep water during the day and migrate to the surface waters at night. They may aggregate in high densities at the surface, known as swarms. Krill are omnivores that feed on other zooplankton, phytoplankton, and marine snow.

[10] This section is based on interpretation of Bergstad et al. (2001), Brown et al. (1979), Davis and Browne (1996), Greene et al. (1998), Kaartvedt et al. (2002), Kristensen (1983), Lass et al. (2001), Sameoto and Cochrane (1996), Sameoto et al. (2002), Vecchione and Galbraith (2001) and records from the Atlantic Reference Centre.

The other mesopelagic invertebrates of The Gully have been little studied but provide important links between the surface environment of The Gully and the ocean bottom. Shrimps (*Acanthephyra pelagica, Sergestes arcticus, Sergia robusta, Pasiphaea multidentata* and *Pasiphaea tarda*) have been collected in or near The Gully. All of these shrimp species can live at depths below 1000 metres. One species, *Sergia robusta*, can live as deep as 5000 metres in the open ocean. Like krill, shrimps from the genus *Pasiphaea* live in deep water during the day and move to the surface at night to feed. They provide food for deep-living fish species. Pandalid shrimps, the species commonly fished commercially, are found in the arms of the Trough, at depths less than 500 metres over soft, muddy bottoms. Like the other shrimp, they move toward the surface at night to feed on smaller crustaceans.

From the frequency that squid-eating whales are seen in The Gully, we know that squid are numerous in the canyon. Many of these squid species are found in mid- and deep-water habitats and are not easily sampled by scientific equipment. The Atlantic Reference Centre has specimens of *Gonatus fabricii*, the squid eaten by northern bottlenose whales in the northeastern Atlantic, that were taken from The Gully. The oceanic squid, *Teuthowenia megalops*, has been recorded from a site near The Gully. There may be up to 18 species of squid and octopi in the canyon, based on research carried out along the slope of the Scotian Shelf and New England.

Much of the fish biomass of The Gully is made up of mesopelagic fishes that are found in the water column, often well below the ocean's surface but above the ocean floor. The most common mesopelagic fishes recorded from The Gully are the lanternfish, in particular the glacier lanternfish (*Benthosema glaciale*). Lanternfish are concentrated in the mouth of The Gully at depths between 500 and 1000 metres. The lanternfish *Lampanyctus* spp., *Ceratoscopelus maderensis* (horned lanternfish), and *Myctophum punctatum* (spotted lanternfish), and species of viperfish and hatchetfish are other prominent mesopelagic species along the Scotian Slope.

Many mesopelagic fishes, including the glacier lanternfish, move to near surface or surface waters at night to feed. When they move to shallower waters, they become prey for species that do not normally occur in deep water, including groundfish species such as cod, haddock and pollock, and marine mammals.

Fish and Invertebrates of the Water Column below 1000 metres (Bathypelagic Species)[11]

Bathypelagic species – animals that live below 1000 metres but above the ocean bottom – have been little studied. Particular species are associated with these depths. Deep-living animals include the giant squid (*Architeuthis dux*), amphipods, shrimps, and fish. In studies of the slope off Nova Scotia, the most abundant bathypelagic fishes have been conger eels. Unidentified percoid fishes were also numerous in samples of the slope, as were anglerfish, in particular *Cryptopsaras couesi*.

Diving Whales[12]

Many species of whales that dive for their prey have been observed over deep waters of The Gully. Two kinds of baleen whales, fin whales and blue whales, are known to dive and feed below surface waters on occasion. Blue whales may dive to depths below 150

[11] This section is based on Davis and Browne (1996) and Zwanenburg (1998).

[12] This section is based on interpretation of Clarke and Kristensen (1980), Croll et al. (2001), Evans (1994), Gowans et al. (2000), Hooker and Baird (1999a, 1999b), Hooker et al. (2001, 2002), Kenney and Winn (1997), Howard (1999) Mead (1989), Panigada et al. (1999), Reeves and Whitehead (1997), Rice (1989), Waring et al. (2001), Whitehead et al. (1992, 1997, 1998).

metres while fin whales dive to depths below 450 metres. The time of day the whales dive is related to the upward vertical migration of krill in the late afternoon and evening. By diving later in the day, whales take advantage of the krill's greater accessibility to the surface. Both species of whales also feed on other animals found closer to the surface.

The toothed whales of The Gully dive in search of squid and fish. The long-finned pilot whale forages at a range of depths for squid, most commonly at depths between 100 and 500 metres but also in surface waters. The dolphins of The Gully range throughout the water column in search of squid and lanternfish. Common dolphins prefer habitat with steep topographic features, like sea mounts and submarine canyons. Their diet in The Gully has not been studied, but in other parts of the world, common dolphins feed on lanternfish and deep sea smelts. They feed in the evening and at night, when these fish are closer to surface waters and are more accessible to the diving dolphins.

Some of the whales found in The Gully dive to depths well below 500 metres. The dives of northern bottlenose whales observed in the canyon have been measured using special devices attached to the whales. They dive to depths greater than 800 metres, and the deepest dive recorded was 1450 metres. Other species of beaked whales observed in The Gully, such as Sowerby's beaked whale, can also dive to great depths in search of squid and deep-living fish.

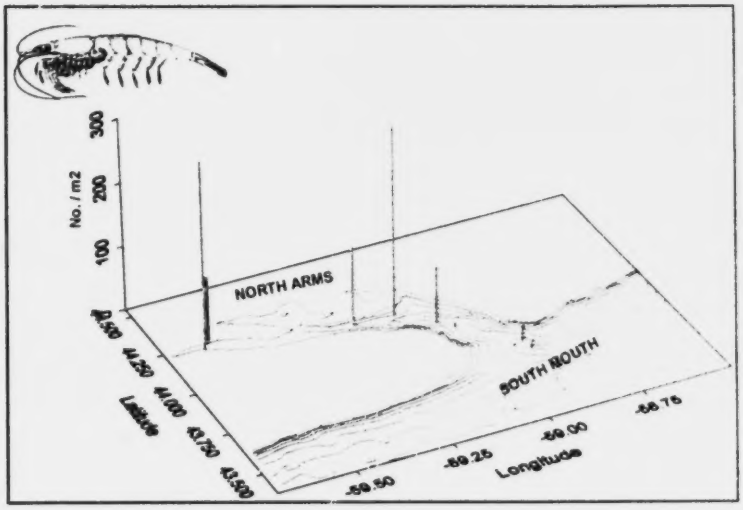

Figure 9. Abundance of krill (*Meganyctiphanes norvegica*) at four stations of The Gully in the spring (red) and fall (green) (from Sameoto et al. 2002).

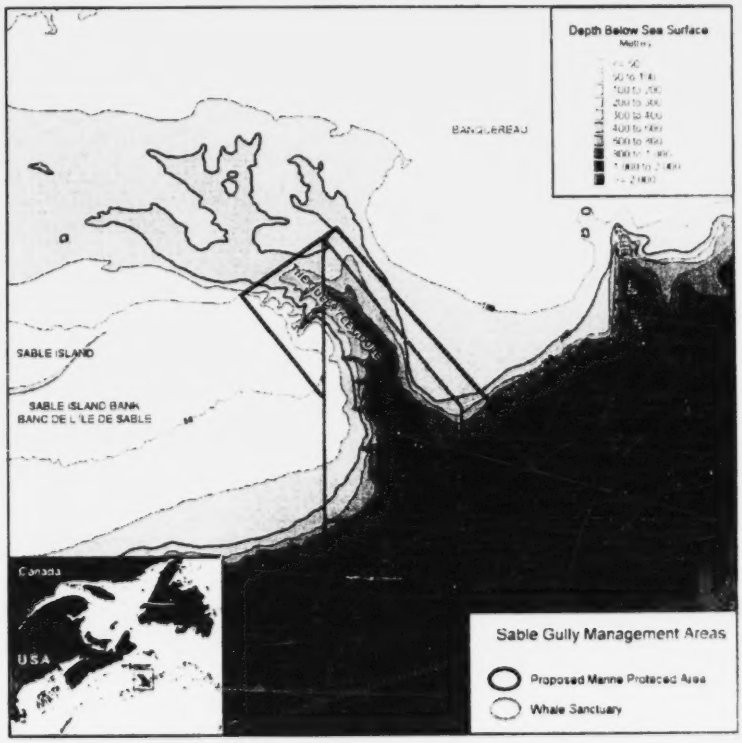

Figure 10. The Gully whale sanctuary is outlined in red. The boundary of the Marine Protected Area of Interest is outlined in black and includes the sanctuary.

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Table 3. Benthic assemblages of The Gully (adapted from Kostylev et al. 2002)	
Physical characteristics	**Species**
1. deep-water (≥ 600 metres), canyon walls, soft muddy sediments, high salinity, low temperature variability, stable environmental characteristics	*Ophiomusium* sp. (brittlestars) *Keratoisis ornata* (banded coral) sea whips (likely *Balticina* sp.) hydroids Alcyonacean corals (likely *Anthomasthus* sp.) anemones clams (*Lima* sp.) stalked crinoids
2. deep-water (250-650 metres), gravelly substrate, influenced by slope water, high salinity, low temperature variability, not very common grouping	*Ophiopholis aculeata* (brittlestar) *Stomphia* sp. (daisy-top anemones) sponges chitons crinoids
3. medium depths (130-410 metres), fine-grained glacio-marine sediments, moderate salinity, moderate water temperature variability, typical species: *Cerianthus borealis*	*Cerianthus borealis* (cerianthid anemone) shrimp (Pandalidae spp. and Crangonidae spp.) burrowing anemones *Meganyctiphanes norvegica* (krill) grenadier flounder
4. shallow depths (50-300 metres), sandy sediments	*Echinarachnius parma* (sand dollar) *Ophiura sarsii* (brittle star) tube-bearing polychaetes *Pagurus* sp. (hermit crab) small attached anemones burrowing anemone (likely *Edwardsia* sp.) gastropods (Trochidae) *Leptasterias* sp. (polar seastars) *Ammodytes* sp. (sand lance)
5. 200-600 metres, tributary canyons, soft and hard sediments (silty sand between cobbles and boulders), steep slope, higher than average salinity, moderate water temperature variability	*Bathysiphon* sp. (large foraminifera) *Amphioplus* sp. (burrowing brittle star) soft corals (Alcyonacea) anemones sponges (incl. *Polymastia* sp.) *Pennatula* spp. (sea feathers)
6. medium depths (100-500 metres), gravelly habitats (sorted till), influenced by shelf waters, lower salinity, moderate water temperature variability	sponges (*Halichondria* sp., *Scypha ciliata*, and unidentified) encrusting and solitary tunicates bryozoans stalked hydrozoa polychaete worms (Sabellidae, Terebellidae) phoronid worms *Buccinum* sp. (whelk)
7. medium depths (100-500 metres), glacial till (poorly sorted), strong currents, average salinity, moderate water temperature variability	similar species to assemblage 6 white encrusting sponges brachiopods (e.g., *Terebratulina septentrionalis*) *Fagesia* sp. (anemones) polychaetes: serpulid worms (*Filograna implexa*, *Protula tubularia*), Nothriidae

Sperm whales are the deepest-diving whale, with dives below 1500 metres recorded in other parts of the world. During the summer, sperm whales are frequently observed in the Trough of The Gully, where water depths are between 200 and 400 metres. Acoustic observations show that they are regularly using deeper parts of the canyon as well, the north and central part of the canyon in particular. The whales feed mostly on medium and large-sized squid. Most of the animals using the area are males, as female sperm whales and calves are usually found south of 40°N and in waters with temperatures above 15° C. A few male sperm whales can be found in The Gully year-round.

Most of the scientific research on Gully whales has focussed on the northern bottlenose whale. The Gully population of this whale is fairly well-studied compared to other populations found in the North Atlantic, and compared to the other whales also found in The Gully.

A population of northern bottlenose whales lives in the canyon year-round. Individual whales move in and out of The Gully, but there are some whales from the population in the canyon all the time. In the area of The Gully, the whales are generally found in waters over depths of 1000 metres or more. Globally, they are rarely seen in waters less than 1800 metres deep. Both adult and immature whales and both females and males are found in The Gully. The whale population is centred over a core area at the mouth of the canyon. In 1994, DFO designated the core area as a whale sanctuary to protect the whales (Figure 10). This designation does not provide legal protection but serves to alert mariners to the presence of whales.

Scientists believe that The Gully's northern bottlenose whales are feeding primarily

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2. deep-water (250-650 metres), gravelly substrate, influenced by slope water, high salinity, low temperature variability, not very common grouping	*Ophiopholis aculeata* (brittlestar) *Stomphia* sp. (daisy-top anemones) sponges chitons crinoids
3. medium depths (130-410 metres), fine-grained glacio-marine sediments, moderate salinity, moderate water temperature variability, typical species: *Cerianthus borealis*	*Cerianthus borealis* (cerianthid anemone) shrimp (Pandalidae spp. and Crangonidae spp.) burrowing anemones *Meganyctiphanes norvegica* (krill) grenadier flounder
4. shallow depths (50-300 metres), sandy sediments	*Echinarachnius parma* (sand dollar) *Ophiura sarsii* (brittle star) tube-bearing polychaetes *Pagurus* sp. (hermit crab) small attached anemones burrowing anemone (likely *Edwardsia* sp.) gastropods (Trochidae) *Leptasterias* sp. (polar seastars) *Ammodytes* sp. (sand lance)
5. 200-600 metres, tributary canyons, soft and hard sediments (silty sand between cobbles and boulders), steep slope, higher than average salinity, moderate water temperature variability	*Bathysiphon* sp. (large foraminifera) *Amphioplus* sp. (burrowing brittle star) soft corals (Alcyonacea) anemones sponges (incl. *Polymastia* sp.) *Pennatula* spp. (sea feathers)
6. medium depths (100-500 metres), gravelly habitats (sorted till), influenced by shelf waters, lower salinity, moderate water temperature variability	sponges (*Halichondria* sp., *Scypha ciliata*, and unidentified) encrusting and solitary tunicates bryozoans stalked hydrozoa polychaete worms (Sabellidae, Terebellidae) phoronid worms *Buccinum* sp. (whelk)
7. medium depths (100-500 metres), glacial till (poorly sorted), strong currents, average salinity, moderate water temperature variability	similar species to assemblage 6 white encrusting sponges brachiopods (e.g., *Terebratulina septentrionalis*) *Fagesia* sp. (anemones) polychaetes: serpulid worms (*Filograna implexa*, *Protula tubularia*), Nothriidae

Sperm whales are the deepest-diving whale, with dives below 1500 metres recorded in other parts of the world. During the summer, sperm whales are frequently observed in the Trough of The Gully, where water depths are between 200 and 400 metres. Acoustic observations show that they are regularly using deeper parts of the canyon as well, the north and central part of the canyon in particular. The whales feed mostly on medium and large-sized squid. Most of the animals using the area are males, as female sperm whales and calves are usually found south of 40°N and in waters with temperatures above 15° C. A few male sperm whales can be found in The Gully year-round.

Most of the scientific research on Gully whales has focussed on the northern bottlenose whale. The Gully population of this whale is fairly well-studied compared to other populations found in the North Atlantic, and compared to the other whales also found in The Gully.

A population of northern bottlenose whales lives in the canyon year-round. Individual whales move in and out of The Gully, but there are some whales from the population in the canyon all the time. In the area of The Gully, the whales are generally found in waters over depths of 1000 metres or more. Globally, they are rarely seen in waters less than 1800 metres deep. Both adult and immature whales and both females and males are found in The Gully. The whale population is centred over a core area at the mouth of the canyon. In 1994, DFO designated the core area as a whale sanctuary to protect the whales (Figure 10). This designation does not provide legal protection but serves to alert mariners to the presence of whales.

Scientists believe that The Gully's northern bottlenose whales are feeding primarily on

squid from the genus *Gonatus*. The movements and life histories of these squid off Nova Scotia are not well understood. However, thousands of tonnes of squid are needed to support the whale population found in The Gully. The huge numbers of squid require an even larger biomass of other animals to feed upon. The Gully is able to support the whales, the squid they eat, and the prey needed by the squid.

The beaked whales from the genus *Mesoplodon* are difficult to see and identify at sea. One species, Sowerby's beaked whale, was identified in The Gully and two other species of mesoplodonts might also be found there. These whales visit the mouth of The Gully, as they prefer the deep water habitats of submarine canyons, the continental slope, and the open ocean. They feed on squids and small fishes.

The size of submarine canyons is an important factor in their use as habitat by whales. Large canyons, such as The Gully, are more highly used by whales than nearby areas and smaller submarine canyons. The Gully's link with the productivity of the adjacent Trough and inner shelf may make it more productive than nearby canyons that do not extend as far into the continental shelf, and thus make it a more popular area for whales. The Gully is able to provide habitat for surface feeding, shallow-diving, and deep-diving whale species. The Gully has both a high diversity and a high density of whales and dolphins, and is one of the most important areas for whales off Nova Scotia.

Organisms of the Ocean Bottom[13]

Many different species are associated with the ocean bottom. Like the organisms of the water column, these benthic animals have different depth preferences. Some prefer to live near the bottom of shallow banks, others prefer to live in the deepest areas of the ocean. Still others are found at a wide variety of depths, where there are appropriate sediments for them to attach themselves to or burrow in. The Gully, with varied depths and sediments, supports a diverse array of bottom-dwelling organisms.

Invertebrates

Some benthic invertebrates, such as soft corals, sea anemones, and scallops, feed by filtering living plankton and detritus from the water. Other benthic animals, such as brittle stars, both filter feed and use other methods to collect food. Many of the filter feeders, such as corals, are attached to the ocean bottom. Other filter feeders, such as scallops, move rarely. These animals thrive in areas where water currents continually move new sources of food past them. Another group of organisms, called deposit feeders, live directly in or on the sediments and feed on organic materials that are deposited on the ocean floor. The Gully and other submarine canyons are areas where organic particles suspended in the water column are more likely to collect than in other parts of conti-

Table 4. Corals of The Gully and nearby areas (compiled from Breeze and Davis 1998, MacIsaac et al. 2001, and Hudson Cruise Report 2001).

Scientific Name	Common name
Alcyonacea	**Soft corals**
Capnella sp.	--
Anthomastus sp.	--
Gorgonacea	**Gorgonian/horny corals**
Paragorgia arborea	bubble-gum coral
Anthothela grandiflora	--
Acanthogorgia armata	--
Radicipes gracilis	--
Acanella arbuscula	--
Keratoisis ornata	gold-banded coral
Paramuricea grandis	black coral
Paramuricea placomus	--
Primnoa resedaeformis	sea corn
Scleractinia	**Stony corals**
Lophelia pertusa (dead fragments only)	spider's nests
Flabellum alabastrum	cup coral
Javania cailetti	--

[13] Based on interpretation of Breeze and Davis (1998), Davis and Browne (1996), Harding (1998), Hecker et al. (1980), MacIsaac et al. (2001), MESD (2001), Scott and Scott (1988), Snelgrove (1991), Strong and Hanke (1995), Vetter (1995), Vetter (1998), Yoklavich et al. (2000), and Zwanenburg and Branton (1998).

nental shelves. This means that The Gully is better able to support high numbers of organisms than if it was solely dependent on the primary productivity generated in the surface waters of the canyon.

Recent research in The Gully has mapped some of the habitats of the upper parts of the area, to a depth of about 500 metres. Researchers have examined photographs and videos of epifauna (animals that live on the sediments of the ocean bottom) taken in The Gully. The species were grouped according to their habitat preferences, such as sediment type, depth, and water characteristics (Table 3). Benthic species seen in the photographs include brittle stars, anemones, gorgonian and alcyonacean corals, and sponges.

The hard glacial substrates of The Gully, such as boulders deposited by glaciers and iceberg pits and furrows, have the most diverse epifauna. These areas may have a greater variety of sediment types and in that way, can provide suitable habitat for a greater number of species. As well, certain organisms, such as encrusting sponges and large gorgonian corals, are only found attached to rocks and boulders. The Gully has a comparatively high number of hard glacial substrates in a small area, and at depths greater than other glacial deposits on the Scotian Shelf.

Scientists have observed at least ten species of corals attached to the terraces and bedrock walls along the sides of The Gully. Other coral species, from scientific research collections or observed by fishermen, have been reported from The Gully and nearby areas (see Table 4). Most corals are found on hard substrates although a few of the smaller species can anchor themselves in soft, muddy sediments. The Gully has the highest diversity of coral species so far observed on the Scotian Shelf.

Some corals found in The Gully may be hundreds of years old and grow to more than a metre in size. The gorgonian *Paragorgia arborea* can be several metres in height. In The Gully, most corals are found deeper than 300 metres. In other parts of the Northwest Atlantic, corals have been found as deep as 2000 metres, so explorations of deep areas of The Gully may find new areas of coral or record species not previously observed in the canyon.

Scientists have not studied the deepest parts of The Gully and the benthic organisms found there are not well-known. They are likely similar to other submarine canyons along the margin of the Northwest Atlantic. Hecker led a study of Oceanographer Canyon, a large canyon indenting the margin of Georges Bank, that surveyed the epifaunal species and grouped them by depth. The researchers found fish, anemones, starfish, sponges, brittlestars, gorgonian and soft corals, and crabs living in the deepest parts of the canyon, from 1100 to 1799 metres.

The epifauna – animals such as starfish, corals and sponges that live on the ocean bottom – can be seen in photographs and from research submarines. The infauna are a different matter. These animals live in the sediments of the ocean floor and feed on particles that drift to the bottom. Many

Table 5. Fish sampled by demersal research trawl in The Gully, 1970-1993, listed by abundance (from Strong and Hanke 1995)

1. Redfish (spp.)	24. Atlantic argentine
2. American plaice	25. Wrymouth
3. White hake	26. Longhorn sculpin
4. Witch flounder	27. Red hake
5. Thorny skate	28. Common ocean pout
6. Cod	29. Northern sand lance
7. Silver hake	30. Capelin
8. Longfin hake	31. Lanternfish
9. Atlantic halibut	32. Rock grenadier
10. Winter skate	33. Offshore hake
11. Haddock	34. Spiny dogfish
12. Marlin-spike	35. Sea raven
13. Smooth skate	36. Little skate
14. Monkfish	37. Atlantic mackerel
15. Pollock	38. Stomiatoid (unidentified)
16. Atlantic wolffish	39. Black belly rosefish
17. Greenland halibut	40. Arctic eelpout
18. Fourbeard rockling	41. Mailed sculpin
19. Yellowtail flounder	42. Unidentified fish
20. Arctic hookear sculpin	43. Short-tailed eelpout
21. Northern hagfish	44. Ogrefish
22. Cusk	45. Roughnose grenadier
23. Atlantic herring	

build burrows or tubes to live in. While some of the tubes protrude above the sediments, there is no visible sign of many of the infauna. These animals can only be observed by collecting and examining sediment samples from the ocean bottom.

In The Gully, very few sediment samples have been taken. However, it is likely home to a high diversity of these animals. Studies of other areas along the continental slope and abyssal plain have found a high diversity of infaunal species. Animals that are found in the sediments of the slope and abyssal plain include polychaete worms, bivalve molluscs, and small crustaceans (isopods and amphipods).

Table 6. Demersal fish species of the Slope 58°W to 60°W (adapted from Zwanenburg and Branton 1998)

Most abundant of fish caught from 180 to 360 metres		
• freckled skate	• monkfish, goosefish, angler	• ocean pout
• little skate	• northern hagfish	• pollock
		• short-fin squid
Most abundant of fish caught from 360 to 900 metres		
• American straptail grenadier	• Gray's cutthroat eel	• round skate
• *Apristurus laurussoni* (Iceland cat shark)	• Atlantic halibut	• shortspine tapirfish
	• Jensen's skate	• snubnose slime eel
• Arctic eelpout	• knifenose chimera	• spiny eel
• Atlantic argentine	• lanternfish (unspecified)	• spinytail skate
• backfin tapirfish		• spotted wolffish
• barndoor skate	• longfin hake	• trunkfish
• cusk	• longnose grenadier	• Greenland halibut (turbot)
• eelpouts (unspecified)	• marlin-spike (common grenadier)	• redfish (unspecified)
	• northern wolffish	• rock (roundnose) grenadier
	• offshore hake	
Most abundant of fish caught below 900 metres		
• roughhead grenadier	• *Apristurus profundorum* (deep-sea cat shark)	• blue hake/blue antimora
• longnose chimera		• black dogfish
	• boa dragonfish	

Fishes

The bottom-dwelling fishes – groundfish – of The Gully that have been sampled by research trawl surveys were caught at depths between 181 and 360 metres (Table 5). Most of these species prefer relatively shallow depths along the sides of the canyon, and are not likely to be found in the deepest parts of The Gully. Groundfish feed on a wide variety of organisms: copepods, euphausiids and other zooplankton; shrimp and other pelagic invertebrates; benthic invertebrates such as polychaete worms; and other fish.

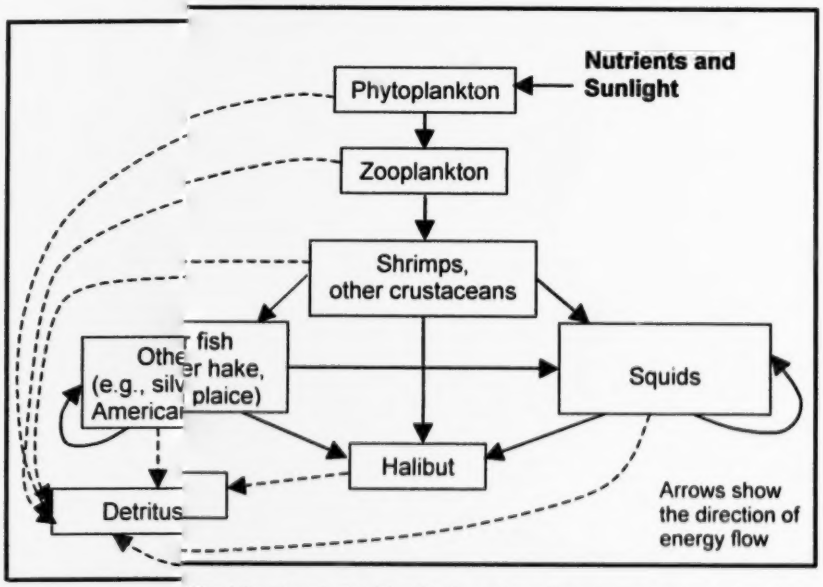
In the 1980s, bottom trawl surveys were carried out along the Scotian Slope and in The Gully to about 900 metres in depth. Pollock, silver hake, and white hake were common species sampled at depths of 180 to 360 metres (Table 6 lists the fish caught and the depth ranges where they were most abundant). At depths of 360 to 900 metres, redfish were the most abundant. Atlantic halibut, longfin hake, and offshore hake were also abundant. At and below depths of 900 metres, black dogfish was the most common species sampled. Few trawls were carried out below 900 metres.

The Gully is well-known as a prime fishing spot for Atlantic halibut. Halibut are abundant along the sides of The Gully below about 200 metres in depth. A simplified food web, with halibut as the top predator, is shown in Figure 11. The features of The Gully appear to make it a preferred habitat for this fish. The Gully is one of the three most important areas for halibut on the Scotian Shelf, based on regular use by fishermen. Halibut populations are hard to estimate since they are not caught regularly by the scientific trawl surveys.

Halibut spawning sites on the shelf edge have not been documented. They appear to spawn near the bottom at depths of at least 183 metres with reports of spawning at depths of up to 1000 metres. Their eggs do not float near the surface, but are suspended in the water column. The vertical distribution of the eggs is dependent on the water's salinity. In other areas, eggs have commonly been observed at depths of 300 to 400 metres, with occurrences as shallow as 50 metres and as deep as 700 metres. The

reproductive characteristics of halibut, combined with the abundant food supply in The Gully and its retention characteristics, make The Gully ideal habitat for spawning and larval halibut.

Cusk are caught more frequently in The Gully than nearby areas. They prefer areas of hard, rocky bottom, deeper than 150 metres, and are not often caught by trawlers. However, they are often caught as bycatch by longliners fishing for halibut in The Gully. Like halibut, their populations are difficult to estimate.



lified food web for The Gully, with a focus on energy flow to

Figure 11. A sim halibut.

Redfish are abundant in The Gully. They prefer depths greater than 360 metres and areas with rapid changes in bathymetry. Small redfish rely on benthic structures such as rocks and large epifauna, to avoid predation. The complex topography of The Gully make it a particularly attractive habitat for redfish. Rock habitats within submarine canyons off California have been found to be refuges from harvesting for rockfish (closely related to the redfish found off Nova Scotia).

THE SIGNIFICANCE OF THE GULLY[14]

Diversity in The Gully

The Gully's great diversity of habitat is significant feature of the submarine canyon Compared to nearby areas of the Scotia Shelf, The Gully has more varied topograph and a greater variety of sediment types. There are steep cliffs, flat terraces, and gentle slopes. There are exposed portions of bedrock, deposits of cobbles and boulders from glaciers, and soft, muddy sediments. Depths range from the ocean's surface to more than two kilometres below it. Many different habitats and communities are found within The Gully. Habitat diversity occurs at the metres or tens of metres scale, compared with kilometres or tens of kilometres scale over much of the shelf. Communities of organisms that are separated by tens or hundreds of kilometres in other parts of the shelf are found within a few hundred metres of each other in The Gully. For example, concentrations of lanternfish are found near areas with concentrations of halibut, and concentrations of whales are found near areas with deep-sea corals.

Preserving landscape diversity is a key step in maintaining biodiversity. Marine ecosystems with greater physical complexity have more ecological niches available than homogeneous ecosystems. This complexity may be played out in different ways, such as a wide range of depths, patches with different sediment types, areas with physical habitat created by organisms, such as shell

[14] This section is based on material presented the previous sections, as well as Boehm (1989 Bothner (1989), Cooper (1989), Gili et al. (1999 Thorne-Miller (1999), Verrill (1882a, 1882 and Whiteaves (1901).

beds and structures created by corals, and areas with patches of water that differ in properties, such as deep basins with warm waters at the bottom and a less stable temperature regime along the sides and near the surface.

Landscape or "seascape" diversity in the ocean environment is more difficult to observe and measure than that of coastal and terrestrial ecosystems. While there has been no dedicated inventory of the diversity of species or habitats in The Gully, there are several indications of The Gully's diversity:

- There is a diversity of sedimentary habitats and topography at the scale of metres or tens of metres, a key factor determining species' distributions.
- A diverse array of fish have been sampled in The Gully by groundfish research trawl surveys.
- The Gully has a diversity of whale species and is targeted by whale scientists for directed research because of its whale populations. It has been identified as an important area for cetaceans.
- It is one of three areas on the Scotian Shelf identified by fishermen as abundant in deep-sea corals.
- A diversity of corals and other filter feeders have been observed or collected there.
- Epipelagic, mesopelagic, bathypelagic, and demersal fishes and invertebrates are all found there.
- The three-dimensional nature of the marine environment means that there is a greater *volume* of available habitat in The Gully compared to similar-sized areas on the shelf.

Although other areas of the Scotian Shelf have a diversity of groundfish, are studied by whale researchers, and have distinct benthic communities, no other single area combines these characteristics.

High Secondary Production

The Gully is a core habitat for deep-water species and the species that they prey on. It is able to support a population of northern bottlenose whales year-round and is used by other whale species. No other area off Nova Scotia has concentrations of bottlenose whales. The Gully is also one of three key halibut fishing areas on the Scotian Shelf, with consistently high catches for more than a century. This means the canyon has a high level of productivity, with large populations of squid, lanternfish, amphipods, shrimps, and many other species supporting predators further up the food chain.

The basis for this high productivity is not solely primary production within The Gully itself, but the organic detritus that pours into The Gully from adjacent banks. Not only are there regular inputs of organic materials from nearby areas, but organic particles in The Gully are subject to frequent resuspension due to the energetic environment of the canyon. This detritus feeds The Gully food chain.

The Gully as a Natural Refuge

Due to the steep slopes, bedrock outcrops, and boulders found in some areas of the canyon, the canyon is a natural refuge for marine fauna. Much of the canyon is inaccessible to fishing gear and it is likely that deep parts of The Gully have been little disturbed by fishing.

Although The Gully has been known as a prime halibut fishing area for over 100 years, the longlines used in that fishery are unlikely to have changed the structure of the bottom environment. This means that The Gully may represent a less disturbed ecosystem than environments that were more accessible to fishing.

The Gully may serve as a refuge for fish such as halibut, cusk and redfish, particularly adults who use the rocks and steep topogra-

phy to rest and hide from predators. In The Gully's steep, rocky habitats, they are also largely protected from fishing gear. Both redfish and halibut are long-lived species that reach sexual maturity at roughly the same time as they reach commercial size. Natural harvesting refuges may increase the number and quality of spawning fish in their populations. Other fish species may also benefit from the refuge provided by The Gully's rough topography.

Silver hake eggs and larvae and lanternfish larvae have been sampled in some numbers from The Gully. Deep water fish whose eggs are meso- or bathypelagic are also likely to use The Gully as a spawning area. For example, halibut is a deep water spawner whose eggs remain suspended in the water column. The retention characteristics provided by The Gully serve to keep fish eggs and larvae in the canyon and near areas of preferred habitat.

The Gully is home to a population of northern bottlenose whales. This population is considered to be of "special concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) due to its small size and proximity to human activities. These whales are not found with regularity anywhere else on the Scotian Shelf. Other whale species also use the canyon regularly.

Connections with other Marine Ecosystems

The Gully is connected with both the continental shelf and the deep ocean. It is closely connected with other marine ecosystems along the Scotian Shelf, the continental slope, and the rest of the Northwest Atlantic. Cool waters from the Gulf of St. Lawrence, from off Labrador and from off Newfoundland are carried south and brought regularly into the canyon. Warm, salty slope waters occasionally leak into the canyon. These currents carry organisms into The Gully from other areas, such as copepods from the Gulf of St. Lawrence and warm water fishes from subtropical waters. Bottom currents carry sediments and organic particles into the canyon from the banks of the Scotian Shelf. Fish, whales, and seabirds travel to The Gully from other marine environments. These connections mean that events happening in other areas can affect The Gully ecosystem.

Processes within The Gully may make it more likely to be affected by pollutants. Fine-grained suspended sediments actively absorb dissolved inorganic and organic contaminants in sea water. A high rate of re-suspension provides more opportunities for absorption to occur. Submarine canyons appear to have more frequent and intense occurrences of particle re-suspension than adjacent slope environments.

In Lydonia and Oceanographer submarine canyons along Georges Bank, higher levels of trace metals have been measured than in adjacent areas. This difference was attributed to a higher rate of re-suspension in the canyon. This has important implications for the discharge of pollutants in canyons and adjacent areas, as canyons are more likely to experience elevated levels of contaminants. The retention properties of The Gully mean that floating particles do not pass directly through the canyon. Contaminants remain within The Gully for some time and become more concentrated there than in adjacent areas.

Scientific Importance

The Gully has been a site of scientific interest for more than a century. Halibut fishermen from Gloucester, Massachusetts collected many marine invertebrates from this general area and brought them to the American scientist A.E. Verrill for his collections. These early collections provided the first records of some of these animals in North Atlantic waters, and in some cases, the first records ever.

The remarkable physiography of the canyon is in itself of scientific interest. The patterns of glacial deposits in the canyon and the depths at which they are found provide information about glacier movements on the shelf. The Gully is being actively maintained as a canyon and observations of the flow of sediments into the canyon and depositional areas provide insights on submarine canyon development in general.

Research on The Gully is providing insights into the workings of submarine canyons along the Scotian Shelf. Protection of this area would allow it to be used as a scientific reference area against which impacts of activities in other areas could be monitored. With little known about the deep water habitats of the canyon, yet their evident importance for whales and other species, it is important that scientists have the opportunity to explore this environment.

Special Features of other Submarine Canyons

Submarine canyons around the world have been studied extensively, and researchers have found unique, special, or unusual features associated with canyon environments. The canyons indenting the continental shelf off California, such as La Jolla Canyon and Monterrey Canyon, have been particularly well-studied. In that area, the continental shelf is narrow and the canyons are quite close to the coast, resulting in a different marine environment than that of The Gully. However, the canyons along the margin of the continental shelf off the northeastern U.S. have also been extensively studied. Like the submarine canyons of the Scotian Shelf, they indent a relatively broad continental shelf and have similar current patterns. Because of these similarities, and their geographic proximity, general findings for these canyons may be applicable to The Gully.

A 1989 conference on the submarine canyons off the northeastern coast of the U.S. found evidence of their importance for marine life. One of the presenters summed up the findings from research carried out in the canyons:

> *Canyons function as important nursery grounds for a wide variety of megabenthic fauna such as shrimps, cancer crabs, lobsters, white hake, cusk, ocean pout, conger eel, tilefish, black-bellied rosefish, etc. They provide shelter that rarely occurs in noncanyon areas of the outer shelf and upper slope for the adults of some 20 species. Our combined canyon studies show that the surficial geologic features of the canyon heads support unique ecosystems, largely because of their highly varied character.*
>
> *We conclude that submarine canyons are complex three-dimensional environments where there is little, if any, impact from active fishing gear; they serve as refugia for many bottom-oriented species. Species diversity and abundance are greater in canyons than in noncanyon areas at comparable depths. Habitat diversity on a scale of a few meters to several kilometres leads to species diversity* (Cooper 1989, p. 6-7).

Large, long canyons along the U.S. northeastern continental shelf, with deep mouths at the shelf break, are more highly energetic environments than smaller, shorter canyons. These large canyons are more likely to be actively maintained as canyons than smaller canyons. More suspended organic materials are deposited within the larger canyons, fuelling enhanced secondary production. The Gully is larger and longer than any of the American canyons studied. Like the U.S. canyons, The Gully has a variety of sediments and diverse habitats. It is a complex, three-dimensional habitat. However, there have been no scientific studies carried out in The Gully on the same scale as the American canyons. For that reason, conclu-

sions from scientific research in The Gully are necessarily more tentative. Nonetheless, because The Gully's features are similar to the U.S. canyons, it likely shares many of the same special characteristics.

Unique features have been found in canyons around the world. Research in a Mediterranean canyon found a rich community of hydroidomedusae (a subclass of hydrozoa), and recorded several new species not previously known to science. La Jolla canyon, off California, has higher densities of leptostracan and amphipod crustaceans than sampled anywhere. In both cases, high levels of organic detritus were seen as the cause of these distinctive features. Some species of whales prefer canyon habitats and large canyons in particular may be important for whales. While their importance for beaked whales has been fairly well documented, other cetaceans also make regular use of submarine canyons around the world, including sperm whales, humpback whales, fin whales, blue whales, bottlenose and common dolphins, and others.

ASSESSMENT[15]

The Gully's suitability for a marine protected area was first suggested in 1992, when Parks Canada identified The Gully/Sable Island area as a natural area of Canadian significance. In 1994, DFO designated The Gully as a whale sanctuary. Conservation groups and whale researchers have advocated the protection of The Gully. After a review of the scientific information on The Gully, it was identified as an Area of Interest under DFO's marine protected area program.

Scientific research programs continue to add to our knowledge of The Gully and have reinforced the initial decision to select The Gully as an Area of Interest. The Gully submarine canyon is an area like no other in Canada, perhaps like no other in the North Atlantic. Protecting The Gully will conserve marine resources and their habitats, protect unique habitats, and protect an area of high secondary biological productivity and biodiversity.

The forthcoming Gully management plan will address issues that affect the health of the canyon. Human activities in nearby areas will affect The Gully ecosystem and this issue will be considered through the Eastern Scotian Shelf Integrated Management (ESSIM) initiative, an oceans planning process for the eastern Scotian Shelf.

[15] The assessment section is based on material presented in the previous sections.

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